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Process parameter influence on Electro-sinter-forging (ESF) of titanium discs

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Abstract

Electro-sinter-forging (ESF) is an innovative sintering process based on the principle of electrical Joule heating. The electrical current is flowing through the powder compact, which is under mechanical pressure. As compared to conventional sintering [1] and spark plasma sintering [2], the main advantages are the decreased sintering time and high relative density [3]. Near net-shape components can be manufactured and post-removal processing is limited to surface polishing. The present work is focused on analysing the influence of the main process parameters, namely compacting pressure, sintering time and electrical current density, on the final density of a disc sample made from commercially pure titanium powder. The maximum achieved relative density was 94% of the bulk density of pure titanium. The density estimation was carried out by using both Archimedes' and 3D scanning.

Case study

Sintering of a small disc made of commercially pure titanium, grade 2 (purity 99.5 %), average particle size 150 µm. The disc has a size of a small cylinder of 10.3 mm diameter and 3 mm thickness. The measurement of the final relative density was carried out as an indicator of the influence on the quality of the different combination of process parameters. Microstructure observations helped in understanding the sintering effect on the powder particles.

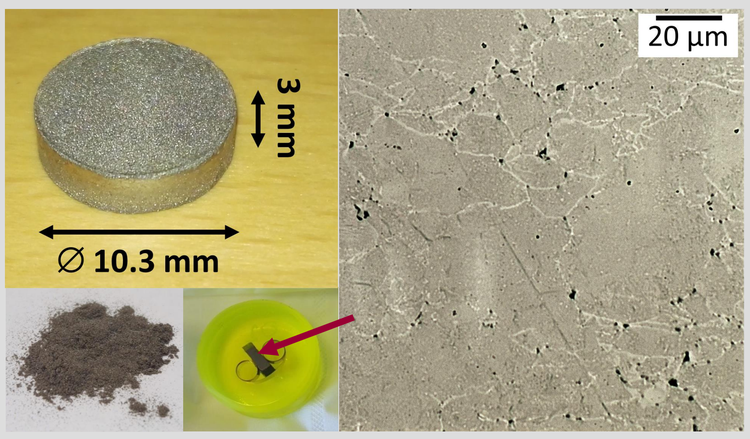

Fig. 1. Raw Ti-powder, sintered sample and micrograph showing the microstructure after sintering.

Experimental setup

- The ESF process takes about 6 s including the following phases: (i) pouring out of the electrically conductive powder, (ii) pre-compaction, (iii) heating by electrical current during 100-200 ms, (iv) cooling, (v) ejection;
- A middle frequency direct current (MFDC) resistance welding machine (Expert 170kVA with Harms & Wende HWI 2000 control unit) was used. High electrical current, up to 115 A/mm^2, was applied;
- The punches acted also as electrodes. They are made of electrolytic copper. The alumina die is electrically insulated to concentrate the current flow in the compact;
- The density analysis was made with the volume measurements obtained from the suspension method and 3D scanning.

Process parameter	Low level (-)	High level (+)
compacting pressure/MPa, P	69	115
sintering time/ms, t	100	200
electrical current density/A/mm^2, E	58	115

Table 1: Experimental sintering parameters.

Methodology

The principle is inspired from electrical resistance welding. The powder is simultaneously subjected to a mechanical pressure and an electrical current. The Joule heating produced from the electrical current flowing into the powder compact allows the sintering of the sample in a reduced amount of time. To allow the current flow into the component, the powder has to be electrically conductive.

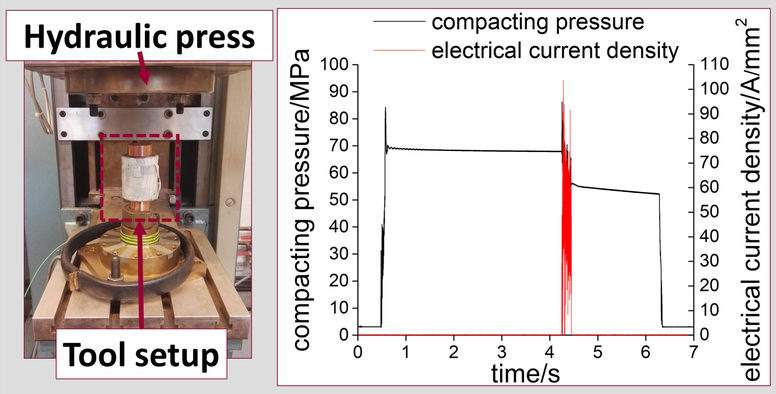

Fig. 2. ESF setup and electrical current and mechanical pressure profiles during an ESF process.

Results

The DoE analysis was done by following a 2^n approach. The investigated process parameters are listed in Table 1. Results in Fig.3 show how the electrical current density is the most influencing parameter for the final density. The largest achieved density was found to be 94% relative to the bulk density. Volume measurements were carried out by using two methods, namely the Archimedes' principle and the 3D volume reconstruction. The two methods are compared in Fig. 4. They show full compatibility of results on the measured density. The uncertainty was estimated taking into account three main contributions:

- Powder weight procedure and balance resolution;
- Volume measurements (Archimedes' method and 3D scanning);
- Density calculation.

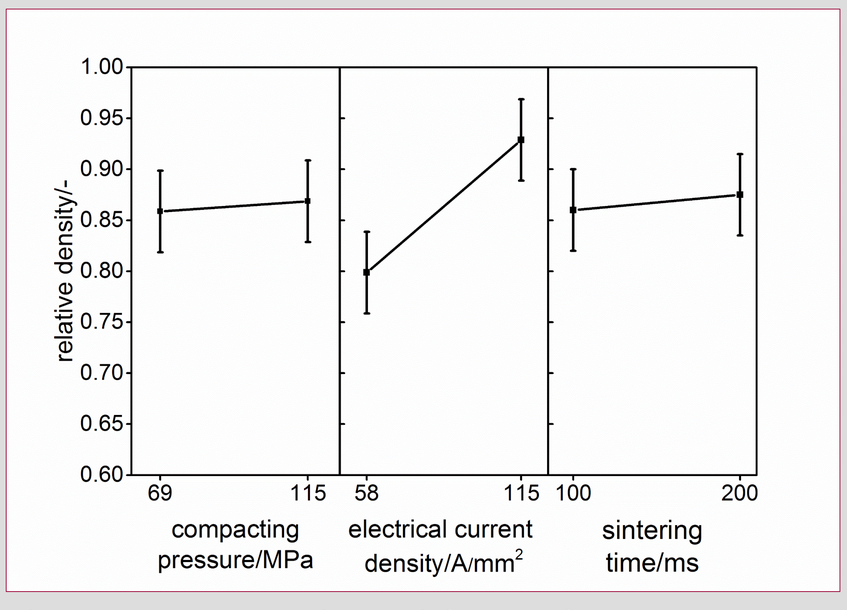

Fig. 3. DoE results showing the influence of process parameters on relative density. Pure titanium density, 4.51 g/cm^3.

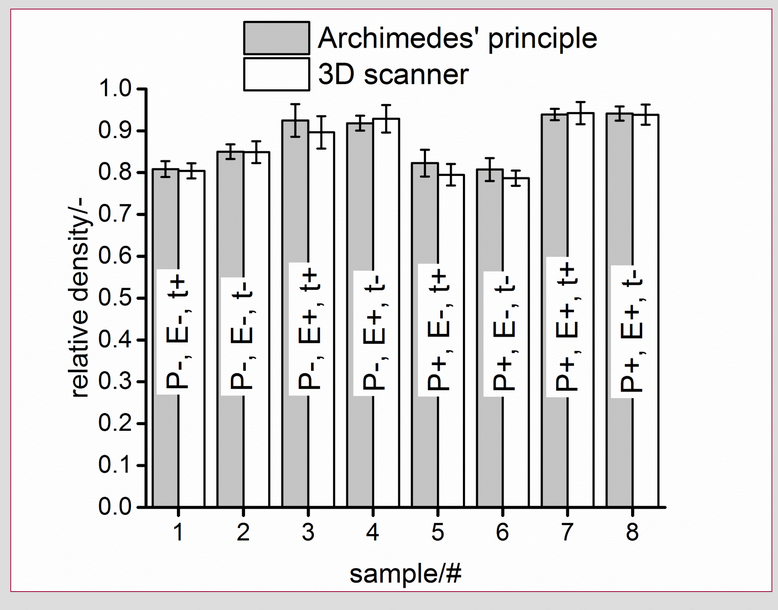

Fig. 4. Comparison between the Archimedes' method and 3D scanning for density estimation.

Conclusions

The electrical current is the most influencing factor in achieving a high sample density for electro-sinter-forging. A highest value of 94% relative density was achieved. The density measurement made by using the Archimedes' method and 3D scannning showed full compatibility. 3D scanning is suggested to avoid problems connected to fluid penetration. Future works could be focused on testing larger process values and different conducting powders.

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